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## **Exogenous attention to unseen objects?**

### **Abstract**

Attention and awareness are closely related phenomena, but recent evidence has shown that not all attended stimuli give rise to awareness. Controversy still remains over whether, and the extent to which, a dissociation between attention and awareness encompasses all forms of attention. For example, it has been suggested that attention without awareness is more readily demonstrated for voluntary, endogenous attention than its reflexive, exogenous counterpart. Here we examine whether exogenous attentional cueing can have selective behavioural effects on stimuli that nevertheless remain unseen. Using a task in which object-based attention has been shown in the absence of awareness, we remove all possible contingencies between cues and target stimuli to ensure that any cueing effects must be under purely exogenous control, and find evidence of exogenous object-based attention without awareness. In a second experiment we address whether this dissociation crucially depends on the method used to establish that the objects indeed remain unseen. Specifically, to confirm that objects are unseen we adopt appropriate signal detection task procedures, including those that retain parity with the primary attentional task (by requiring participants to discriminate the two types of trial that are used to measure an effect of attention). We show a significant object-based attention effect is apparent under conditions where the selected object indeed remains undetectable.

## General Introduction

Historically, visual attention and visual awareness have often been viewed as being so intimately related that they may be considered aspects of a single underlying process. It is now well established that this is not the case – attention and awareness dissociate under many conditions (McCormick, 1997; Kentridge, Heywood & Weiskrantz, 1999, 2004; Kentridge, Nijboer & Heywood, 2008; Bahrami, Carmel, Walsh, Rees & Lavie, 2008; Kanai, Tsuchiya & Verstraten, 2006). There is some ambiguity, however, in classic experimental designs manipulating spatial attention (e.g. Posner, 1980) as to whether the unit of attentional selection is a region of space or the object that occupies that space (see e.g. Mole, 2008). One might be perfectly aware of attending to a spatial location even when stimuli appearing at that location remain unseen.

This ambiguity is resolved in tests of object-based attention. In this form of attention the ‘object’ of selection is explicitly provided by the experimenter and it is easy to distinguish between effects that are purely spatial and those involving selection of the cued object. For example, in the paradigm used by Egly, Driver & Rafal (1994) a visual transient directs subjects’ attention to one of two objects. The objects are arranged so that the effect of cueing can be compared for targets at two locations in the display. Both locations are the same distance from the cue but one target location is within the cued object (within-object location) whereas the other is encompassed by the uncued object (between-object location). The target within the cued object gains an attentional advantage over the target in the other object. This advantage cannot be the result of a simple spatial effect as both targets are equidistant from the cue and it is now well established that it is the object that is selected by attention in this paradigm (Reppa, Schmidt & Leek, 2012). If attention acts by selecting objects as a whole then all parts of the cued object should be attended. We

recently adapted the Egly *et al* paradigm and found that masked objects could act units of attentional selection and yet remain unseen (Norman, Heywood & Kentridge, 2013).

There are, however, two forms in which attention can be directed to an object – endogenously and exogenously. William James (1890) described the essential distinction between these two forms of attention: the first is voluntary whereas the second is reflexive . For endogenous attention, in behavioural experiments the cue typically takes the form of something symbolic (e.g. a centrally presented arrowhead), and the likelihood with which this stimulus correctly indicates an upcoming target's location is varied. At high likelihoods, an observer will benefit from and is therefore strongly encouraged to utilise the cue, whereas a neutral cue can be selectively ignored (Giordano, McElree & Carrasco, 2009). For exogenous attention, typically a peripheral cue (i.e. a transient luminance flash) is shown before the target, which observers are unable to ignore even when it is of no informative value (Giordano *et al*, 2009). Many qualitative and quantitative differences (e.g. Briand, 1998; Lu & Doshier, 1998, 2000) support the distinction of purely endogenous and purely exogenous attention, the crux of which is that endogenous attention is under top-down control and is determined by learned associations, whereas exogenous attention is not - it is automatic and rapid.

There remains some controversy over the generality of the dissociation of attention and awareness across these two forms of attention. In particular, recent work by Chica and Bartolomeo (e.g. Chica, Lasaponara, Chanes, Valero-Cabré, Doricchi, Lupiáñez *et al*, 2011; Chica, Botta, Lupiáñez & Bartolomeo, 2012; Chica, Paz-Alonso, Valero-Cabre & Bartolomeo, 2012) suggests that the coupling of attention and consciousness is much stronger when attention is under exogenous, as opposed to endogenous, control. That is, only when attention is captured automatically by external events (exogenously controlled), rather than

voluntarily directed by the observer (endogenously controlled), is it not sufficient for awareness. It is this latter form of attention, and the fronto-parietal network that underpins it anatomically, where Chica *et al* (Chica, Paz-Alonso *et al*, 2012) also show common engagement in attention and awareness. The question arises as to whether any stimulus selected reflexively in response to a visual transient necessarily enters awareness.

Chica *et al* do not assume that stimuli attended under exogenous control inevitably elicit awareness. In a recent experiment (Chica, Botta *et al*, 2012) they have, however, shown that when both endogenous and exogenous attention produced behavioural effects in a reaction time task only exogenous attention produced a reliable change in conscious reports of the targets. Is there any evidence that targets that gain a measurable attentional advantage under exogenous control can remain unseen? There have been some demonstrations that exogenous attention can modulate the processing of unseen stimuli (Hsu, George, Wyart & Tallon-Baudry, 2011; Bahrami *et al*, 2008) and attention has been shown to be deployed to unseen stimuli in a feature-based manner, where visual targets are selected on the basis of a single attribute (e.g. colour or shape), in a manner that is rapid and not dependent on learning (Schmidt & Schmidt, 2010). There is also some evidence from the neurological condition 'blindsight' that stimuli which gain a processing advantage as a consequence of attention guided by visual transients can, nevertheless, remain unseen (Kentridge *et al*, 1999). The cues in this study, although peripheral visual transients, were predictive of target locations and so attentional control was not necessarily exogenous. Nevertheless, in one experiment attention continued to be drawn to targets at the location of the cue for hundreds of trials even when the contingency between cue and target locations was negative (targets were more likely to appear at an uncued location at a rate of 68.75%). This is certainly indicative of exogenous control. Blindsight is a rare condition and

there is evidence for substantial cortical reorganisation in the patient who was the subject of this study, so general claims for dissociation between exogenous attention and awareness on this basis must be treated with caution.

Both Marzouki, Grainger & Theeuwes (2007) and Van den Bussche, Hughes, Van Humbeeck & Reynvoet (2010) assessed the effect of exogenous attentional cues on the efficacy of masked primes in normal observers. In both studies there was no contingency between the location of cues and of primes (that is, cues were not predictive of prime location and so any attentional effect should be purely under exogenous control). Cueing significantly modulated the efficacy of primes indicating an effect of exogenous attention. In both studies it is, however, not clear whether the primes, despite being masked, were rendered completely invisible. In Marzouki *et al* (2007) there is good evidence that the *identity* of the primes was not discriminable but subjects' ability to simply detect the presence of primes was not tested. In Van den Bussche *et al* (2010) a signal detection task testing discriminability of presence *versus* absence of primes showed overall significant but weak prime detectability ( $d' = 0.17$ ). There was, however, considerable variation across observers both in prime detectability and in cueing effects. A regression of discriminability against attentional reaction time advantage (a Greenwald analysis, see e.g. Greenwald, Draine, & Abrams, 1996) showed that within this variability an attentional effect remained where primes were undetectable (at  $d'=0$ ). The subset of observers in whom discriminability was at chance ( $d'\leq 0$ ) still showed an effect of attention. One might, however, still exercise some caution about such *post-hoc* selection. So again, there is evidence suggestive of dissociation between exogenously controlled attentional selection and visual awareness but one that is not absolutely conclusive.

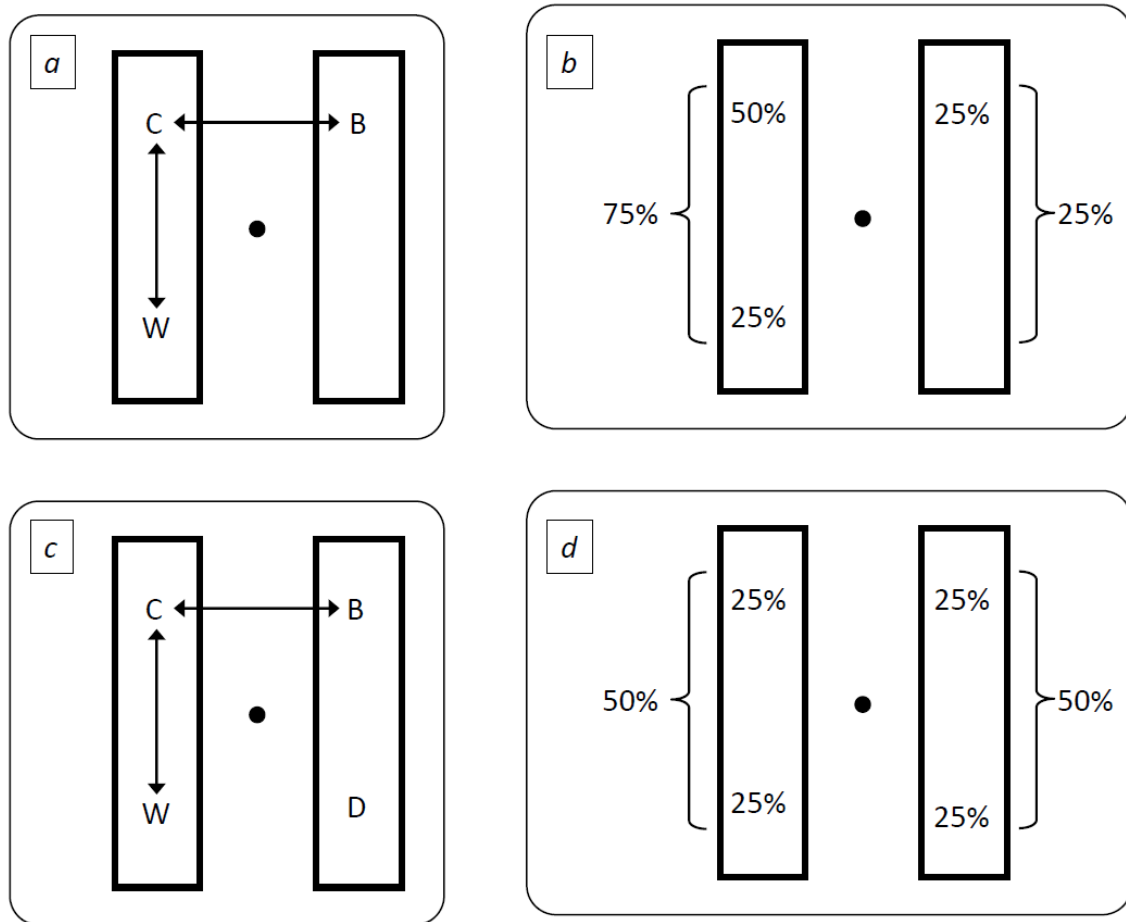
The aim in this paper is to assess whether an *object* selected on the basis of exogenously controlled attention can remain unseen in normal observers and yet influence behaviour. The paper is in two parts. In the first section we present evidence for just such a dissociation together with signal detection evidence that the selected objects remain unseen. In the second part of the paper we compare a number of approaches to constructing signal detection tasks that vary in terms of the comparability of these secondary tasks with the primary attentional task in terms of informational demands made on the subjects.

### **Introduction Experiment 1**

The Egly *et al* object-based attention paradigm is often thought of as being mediated by purely exogenous attentional processes. This may not, however, be the case. Some types of attentional cue can elicit behavioural effects that are simultaneously suggestive of both endogenous and exogenous processing (e.g. eye gaze – Friesen & Kingstone, 1998; Driver, Davis, Ricciardelli, Kidd, Maxwell & Baron-Cohen, 1999; McKee, Christie & Klein, 2007). Most importantly, when a peripheral cue (i.e. an ‘exogenous’ cue) predicts targets in locations remote from the cue itself, then facilitation can be seen in this region (Lambert, Naikar, McLachlan & Aitken, 1999). As this involves the learning of a contingency to successfully interpret and use the cue it cannot be engaging purely exogenous attentional processes. Indeed, some have argued for an entirely separate form of attention known as ‘automated symbolic orienting’ to explain such instances (Ristic & Kingston, 2012). The object-based attention in the classic Egly *et al* paradigm could potentially be controlled in this manner.

At first glance the Egly *et al* paradigm does not appear to include obvious contingencies between cue and target locations. The targets appearing at the two ‘between’ and ‘within’ object locations equidistant from the cue occur with equal probability (see Figure 1). There is, nevertheless, a contingency which might drive implicit learning of an object-based selection strategy. In our version of the task (Norman *et al*, 2013) targets appeared at the within and between target locations on 25% of trials each and at the location of the cue itself on 50% of trials. Responses to the cued location do not form part of the test for object-based attention as there is an obvious confound between spatial- and object-selection for the target. Nevertheless, the high reliability of the cue itself means that targets appear three times as often within the same object as the cue (50% valid plus 25% within object invalid conditions) as they do in the other object (25% between objects invalid condition). This is typical of object-based attention task designs (in the original Egly *et al* task the split was 12.5%, 12.5%, 75%), but Lee, Kramer Mozer & Vecera (2012) manipulated cue-object contingency and showed that when the target appeared equally likely on the cued and non-cued object, thus nulling the contingency, participants were still faster at responding to targets in the cued object. In our earlier paper we took an alternative strategy that avoided this issue (making the locations of the objects themselves unpredictable). Here, in order to directly determine whether an object selected under exogenous attentional control can remain unseen yet influence behaviour, we modify our procedure in a manner akin to Lee *et al* (2012) so that there is no contingency between cue and target locations. We use four potential target locations, two within the cued object and two in the other object. Targets appear with equal likelihood at each location.





**Figure 1** Illustration of the nature of the object-based contingency in the standard Egly *et al* (1994) design. **a.** In the standard display two rectangles flank a fixation cross and on each trial a peripheral cue appears at one end of one of the rectangles (shown in the figure as C). A target then follows in one of three locations – the same location as the cue (C), the opposite end of the same rectangle (W – for “within”) or the adjacent end of the opposite rectangle (B – for “between”). The object-based attention effect is measured as the difference in reaction times to these latter two conditions (note that the arrows indicate that they are equated in terms of spatial distance from the cue). **b.** With the standard design, however, the target appears more often on the object that is cued (the typical percentages of trials associated with each trial type are shown here, in which case the target falls on the cued object three times as often as the non-cued object – 75% compared to 25%). **c.** The design that we use in this study to eliminate this contingency includes a fourth target-location condition (D – for “diagonal”, in which the target appears on the opposite end of the opposite object) and presents an equal number of all four trial types. **d.** With our design it is clear that there is no such contingency, as the target falls on both the cued and non-cued object 50% of the time.

## **Experiment 1 – removing object-based contingencies**

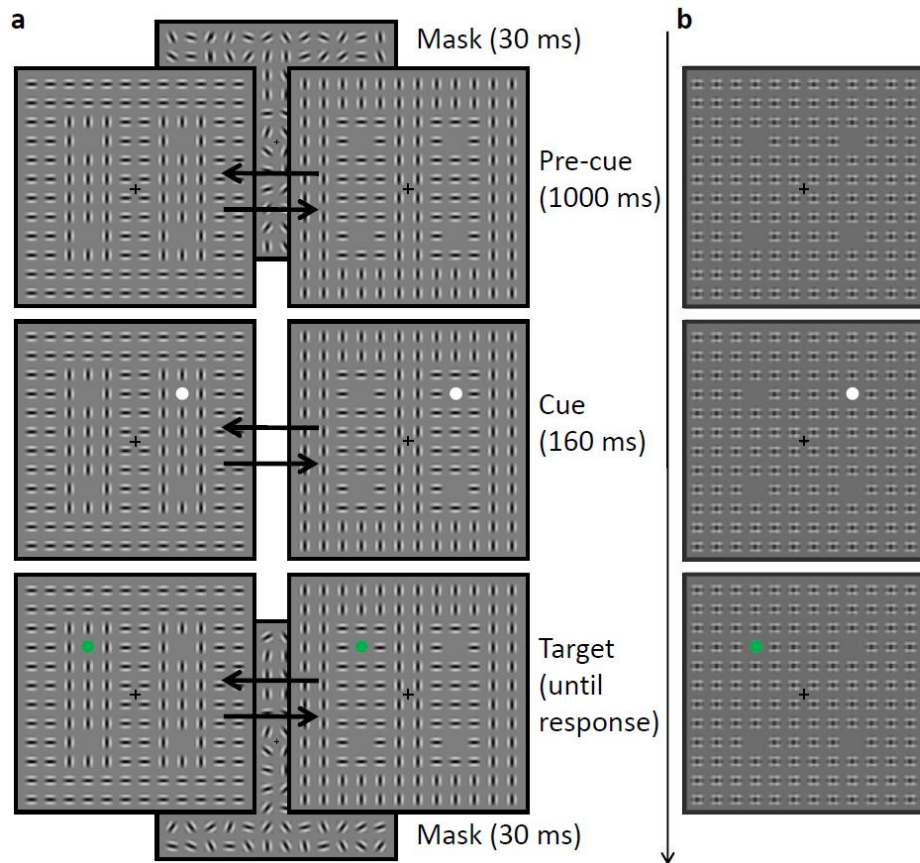
### *Methods*

#### *Participants*

Twenty naïve participants took part (16 female, 4 male; mean age = 20 years, SD = 1.17), and all gave their written informed consent. Participants were students recruited through the Durham University Psychology department's participant pool scheme, and were awarded course credits for their participation.

#### *Materials*

Stimuli in all experiments were generated using a Cambridge Research Systems ViSaGe Graphics System and were presented on a gamma-corrected ViewSonic 17" display monitor viewed at a distance of 41cm (participants rested their head on a chin rest). The background had a luminance of 50cdm<sup>-2</sup>. The screen resolution was set to 1024 x 768 pixels with a refresh rate of 100Hz. The ViSaGe Graphics System ensured that stimulus display and response timing were time-locked with the monitor's refresh rate.



**Figure 2** Illustrations of the stimuli in experiment 1; a simulated observer's perception of those stimuli. **a)** Full illustration of the trial sequence of experiment 1. Note that there are fewer Gabor patches used to produce the objects in the illustration than in the actual experimental stimuli. Here the target (the red or green coloured disc) is invalidly cued between objects. The cue is represented by the white disc. Double arrows indicate that the two frames are presented continually in alternation at a frequency of 16.7 Hz. **b)** A simulated observer's perception of the sequence shown in figure **a**. Participants are not aware of the presence of the figures.

### Procedure

Participants fixated a central cross. Following a warning tone, a lattice (21° in width and in height) centred on the fixation cross consisting of 18 x 18 uniformly positioned Gabor patches appeared. Each Gabor had a diameter of 0.6° and a spatial frequency of 2.7 cycles/degree and was separated from its neighbours by 0.6°. Each Gabor had a maximum

contrast of 100% with a Gaussian standard deviation of  $0.2^\circ$ . See **figure 2** for illustrations of the stimuli and procedure. These Gabor patches were presented for 30ms, each with a randomly determined orientation, as a mask before the onset of the objects. Immediately following this, the Gabors would continually alternate between vertical and horizontal orientations at 16.7Hz. Two identical rectangular objects (measuring 12 x 3 Gabor patches and presented 2 Gabor patches either side of fixation) were formed by an orientation contrast of  $90^\circ$  to the background. Thus, the objects were always defined by an orientation contrast of  $90^\circ$  to that of their background even as the orientations of *all* the Gabors in the display alternated. In half the trials the pair of objects was vertical and in the other half was horizontal, and these trials were randomly interleaved. In four of the positions in the lattice, located 6 Gabor spaces vertically and horizontally in from the four corners, no Gabors were presented, as these locations served as placeholders for cues or targets. Thus, one placeholder was located at either end of both figures.

Objects were presented for 1000ms, followed by a cue (white disc (luminance =  $158 \text{ cdm}^{-2}$ ),  $0.4^\circ$  in diameter) which appeared for 160ms in one of the four placeholders (determined randomly with equal probability on each trial). Following the offset of the cue, the target disc ( $0.4^\circ$  in diameter) appeared in one of four locations, and was either red (CIE 1931 x, y coordinates of 0.40, 0.31 with a luminance of  $72 \text{ cdm}^{-2}$ ) or green (CIE 1931 x, y coordinates of 0.30, 0.59 with a luminance of  $81.06 \text{ cdm}^{-2}$ ). In valid trials (25% of all trials) the target appeared in the same position as the cue. In invalid-within trials (25%) the target appeared in the adjacent placeholder that was within the same figure as the cue had been. In invalid-between trials (25%) the target appeared in the adjacent placeholder that was within a different figure. In invalid-diagonal trials (25%) the target appeared in the diagonally opposite placeholder, therefore within a different figure as the cue. The colour

of the target was determined randomly with equal probability on each trial. Participants were instructed to indicate the colour of the target disc by pressing one of two buttons. The target remained on the screen until a response was made, following which the noise mask of random orientations was presented again for a further 30ms, ending the trial. See **figure 1** for a depiction of the display sequence and a simulation of the observers' perception during the sequence, respectively.

Participants completed one practice block followed by 4 test blocks of 96 trials. Following the completion of all sessions participants were asked a series of questions designed to probe awareness of the presence of figures in the display. Participants then also completed a signal detection task in which they were required to explicitly detect the presence of the objects. Participants completed two blocks, of 140 trials each, in which on each trial they were presented with the flickering background which contained the objects on half the trials. These trials were randomly interleaved with those in which the background was completely uniform (i.e. all of the orientations in the display simultaneously alternated between horizontal and vertical). For those trials in which the objects were present, there were an equal number of horizontal and vertical trials. The display duration was automatically determined individually for each participant by obtaining their largest RT from the attention task following the removal of outliers (removal criteria described in full in the **Results** section), after which the stimuli were masked in the same manner as previously described. The participant indicated with one of two buttons whether the objects were present or absent, and then rated their confidence of that judgment on a scale of 1-4.

### *Results and discussion*

Data from one of the participants are not reported in any analyses because the goodness of fit for fitting parameters in the  $d_a$  estimation was significantly low ( $p=0.018$ ).

Incorrect responses in the target-identification phase were excluded from analyses, and the remaining RTs were trimmed by first removing those that exceeded 1500ms or were less than 150ms, interpreted as unsuccessful button-presses or anticipatory response, and then excluding those that fell outside 2 standard deviations from the mean *per condition per participant* were removed as outliers. This resulted in excluding 7.5% of trials. A repeated measures ANOVA revealed a significant main effect of cue validity on RT ( $F_{(3,54)}=17.647$ ,  $p<0.001$ ), where the overall means were 414.1ms (valid), 426.5ms (invalid-within), 432.7ms (invalid-between) and 433.0ms (invalid-diagonal), as shown in **figure 3**. In the key analysis, a paired t-test revealed that RTs were shorter on invalid-within than for invalid-between trials ( $t_{(18)}=2.748$ ,  $p=0.011$ ), indicating a standard object-based attention effect. No significant effect of accuracy was found between the conditions of cue validity ( $F<1$ ); this indicates no trade-off between RT and accuracy.

Sensitivity was calculated by tabulating the number of responses for each of the eight confidence levels (4 ratings for both “present” and “absent” responses) for both “present” and “absent” trials. The discriminability index  $d_a$  was calculated from these data using the software RScorePlus (Harvey, 2002) to fit a Gaussian unequal variance model.  $d_a$  allows for unequal variance and is equivalent to  $d'$  in the case of equal variance. A higher  $d_a$  indicates a greater sensitivity to the target, and a  $d_a$  of zero indicates no sensitivity. Overall, the average  $d_a$  was low (0.05, with average 95% confidence intervals of  $\pm 0.062$ ), and it was not significantly above zero ( $t_{(18)} = 1.84$ ,  $p = 0.082$ ), indicating that participants could not discriminate the signal (objects) from the noise (no objects). Receiver operating characteristics (ROCs) were also computed from the same data for each participant. Each curve contains 7 points (as a scale of  $n$  criteria, in this case 8, determines  $n-1$  points on the curve), with each representing a single criterion that distinguishes one rating from the

immediately lower rating (e.g. rating 4 from rating 3, or rating 8 from rating 7). The ROC curves are plotted with true positive rate (hit rate) vs. false positive rate (false alarm rate) in **figure 3**; the more linear the plot, the less able the observer is to differentiate the two conditions. As shown in **figure 3**, no participant showed any ability to maximise hit rate whilst minimising false alarm rate (as would be indicated by a bowed curve), indicating that they could not accurately distinguish the conditions that were driving the object-based attention effects in the previous task.

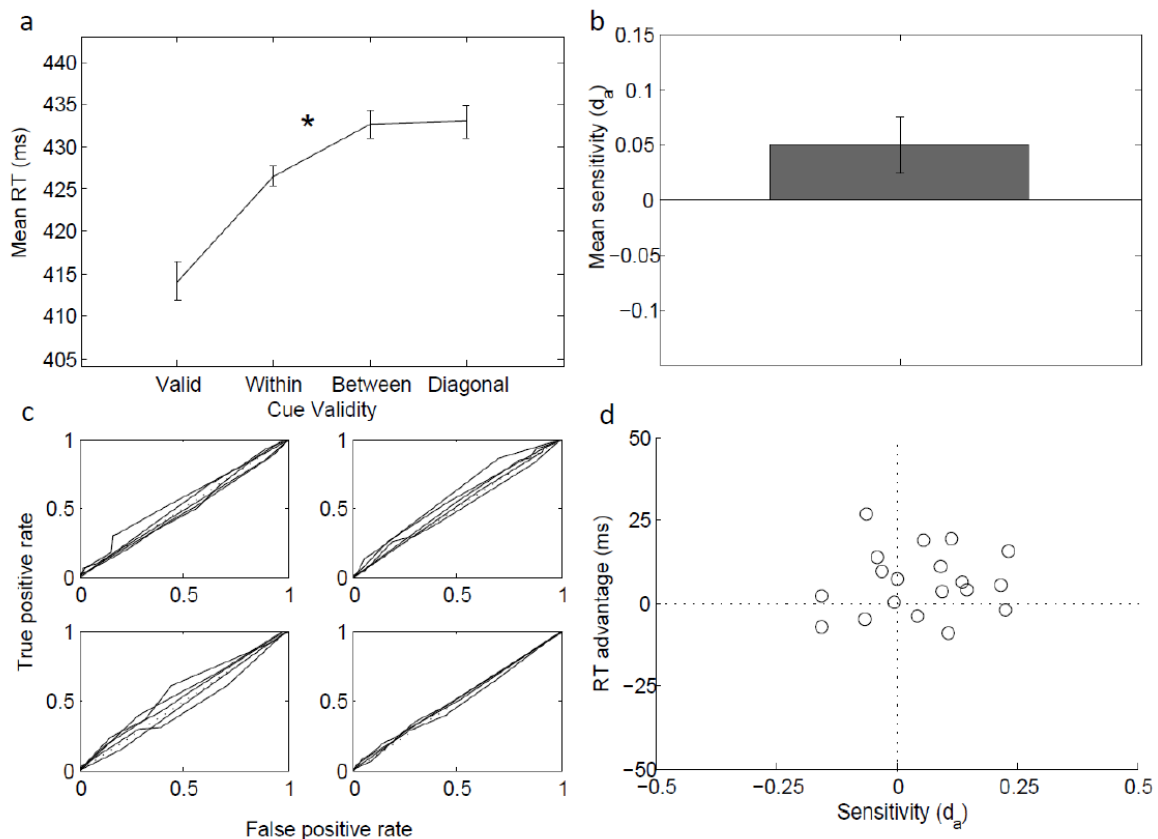
Given that part of our conclusion results rests on accepting the null hypothesis ( $H_0$  – participants have no awareness of the objects) and rejecting the alternative hypothesis ( $H_1$  – participants have some awareness of the objects) based on a non-significant statistic, it is important to demonstrate that this non-significant finding is not simply the result of inconclusive data. For the observed non-significant  $d'$  value it is possible to perform a Bayesian model comparison and to calculate an index known as a Bayes factor which represents a ratio in the likelihoods of competing hypotheses. This can be used to differentiate between data which is inconclusive and data which is positively in support of the null hypothesis. Calculating a Bayes factor requires a specification of what each of the models (or hypotheses) predicts. In this case, this involves comparing a model in which participants are not able to detect the objects (i.e. an average  $d'$  of zero) to one in which they are able to detect the objects (i.e. a  $d'$  score of some value above zero). Given the uncertainty in the experimental literature concerning the nature of the relationship between  $d'$  and subjective awareness (e.g. Vermeiren and Cleermans, 2012) it is difficult to conceive of the parameters of a theoretical model in which participants are aware of the objects. Nonetheless, we compared our  $H_0$  model with a model of  $H_1$  in which participants are able to detect the objects but with very low sensitivity ( $d'$  is uniformly likely to fall

between 0.1 and 0.3). Following the guide of Dienes (2011), we performed a Bayesian model comparison based on these parameters and calculated a Bayes factor of 0.26. The scale of the Bayes factor ranges from 0 (overwhelming support of  $H_0$ ), through 1 (inconclusive), to infinity (overwhelming support of  $H_1$ ) and, as Jeffreys (1961) suggests that values less than one-third represent substantial support for  $H_0$ , we are confident in concluding from our non-significant result that it was extremely unlikely that participants had any experience of the objects.

**Figure 3** also shows a scatterplot of points for each individual participant's within-object RT advantage (calculated from between-object RT – within-object RT) *versus* sensitivity ( $d_a$ ). A parametric correlation test between these two variables is not significant ( $r(18)=0.086$ ,  $p=0.720$ ), clearly indicating no association between the awareness of the objects and their effect on attention.

This experiment demonstrates that object-based attention can occur in the absence of awareness. Importantly, because there was no contingency between the cued-object and the location of the target, this was a purely exogenous form of object-based attention, as shown in Lee *et al* (2012). This result, therefore, supports the position that the modulation of unconscious visual processing by attention is not limited to those forms of attention that are purely endogenous.





**Figure 3:** Results from both the attention task and signal-detection task from experiment 1. **a)** RT results from the attention task (N=19). Participants were quicker to identify the colour of a target when it appeared within the same object as a preceding cue compared with when it appeared on a different object, whilst spatial distance was equated. This is true despite participants denying any awareness of those objects and despite there being no contingency between the objects on which the cue and target appear. Asterisk denotes a significant paired t-test at the 5% level. Error bars show 1 standard error of the mean with between-participant variance omitted **b)** Average sensitivity ( $d_a$ ) to the difference between within- and between-object trials. This value is not statistically different from 0, indicating absence of awareness. **c)** Individual participants' ROC. All participants show an approximate linear plot indicating that they could not successfully maximise hit rate whilst minimising false alarm rate. The lower right set of axes represents 4 of the total 19 participants' ROC curves and the other three each represent 5. **d)** Scatterplot of each participant's RT advantage (between-object RT - within-object RT) *versus* sensitivity. There is no observable association between the participants' ability to discriminate within-object trials from between-object trials and their difference in RT between the two conditions.

## Introduction experiment 2

The results of the previous experiment demonstrated that exogenous object-based attention can operate without awareness. Such a conclusion, however, depends on the robustness of methods used to assess participant's awareness in the signal-detection task. Appropriate means of assessing awareness requires consideration of a number of issues (Vermeiren & Cleeremans, 2012; Lin & Murray, 2014). The validity of the sensitivity measurement (i.e.  $d'$ ) is often restricted to the type of task used. Some researchers rightfully argue for complete parity wherever possible between tasks that independently measure direct and indirect access to a cue (Reingold & Merikle, 1988). In addition to taking such measures, however, Vermeiren and Cleeremans (2012) argue that the two tasks should only be considered equated when the distribution of attention in each task is the same. For example, observers are often instructed to discriminate some property of a stimulus in a signal detection task evaluating awareness when they had not been informed of the presence of this same stimulus in a preceding task measuring the effect of that stimulus on performance. In the awareness task observers will intentionally direct their attention to the stimulus in a way that they could not when its effect on performance was being measured. Perceptual sensitivity to the stimulus is likely to be overestimated in the awareness task. Similarly, the relevance criterion, or information criterion (Shanks & St John, 1994), states that an assessment of awareness is only suitable when it targets the specific information that determines a supposed non-conscious effect.

In Norman et al (2013) we used the most straightforward measure of awareness – a test of participants' ability to discriminate objects' presence *versus* their absence. The critical property that determines the unconscious attention effect, however, is the objects' spatial location and orientation together with the relative positions of the cue and target on

each trial. Even if participants are unable to discriminate the presence and absence of objects *per se* they might conceivably retain a conscious impression as to whether cues and targets appeared within a single object. It could be argued, therefore, that in the signal detection task, participants should in fact be required to discriminate “within-object” from “between-object” trials, on the basis that this maximises the parity between the tasks measuring attention and awareness in terms of the critical aspect of the stimuli that drives the implicit effect.

In the following experiment participants completed a standard Egly *et al* (1994) cueing task and the objects appeared at unpredictable locations and assumed unpredictable orientations on a given trial (as in Norman *et al*, 2013). Awareness was then assessed by first revealing to the participants the nature of the objects and requiring them to view the stimuli from the attention task a second time. In this second phase, participants made a decision on each trial as to whether the cue and target appeared within a single object or in different objects in a confidence-rating signal-detection procedure. This approach maintains parity of stimulus relevance as much as possible between the two tasks. In order to allow accurate comparisons between the results from the following experiment and that used previously (Norman *et al*, 2013), we use the original three cueing conditions used in that experiment (valid, within- and between-object).

## **Experiment 2 – assessing awareness whilst maintaining parity of stimulus relevance between the attention and detection tasks**

### *Methods*

#### *Participants*

Twenty naïve observers (12 female, 8 male; mean age = 20.4 years, SD = 1.01), were recruited, as in Experiment 1.

#### *Materials*

See previous experiment.

#### *Procedure*

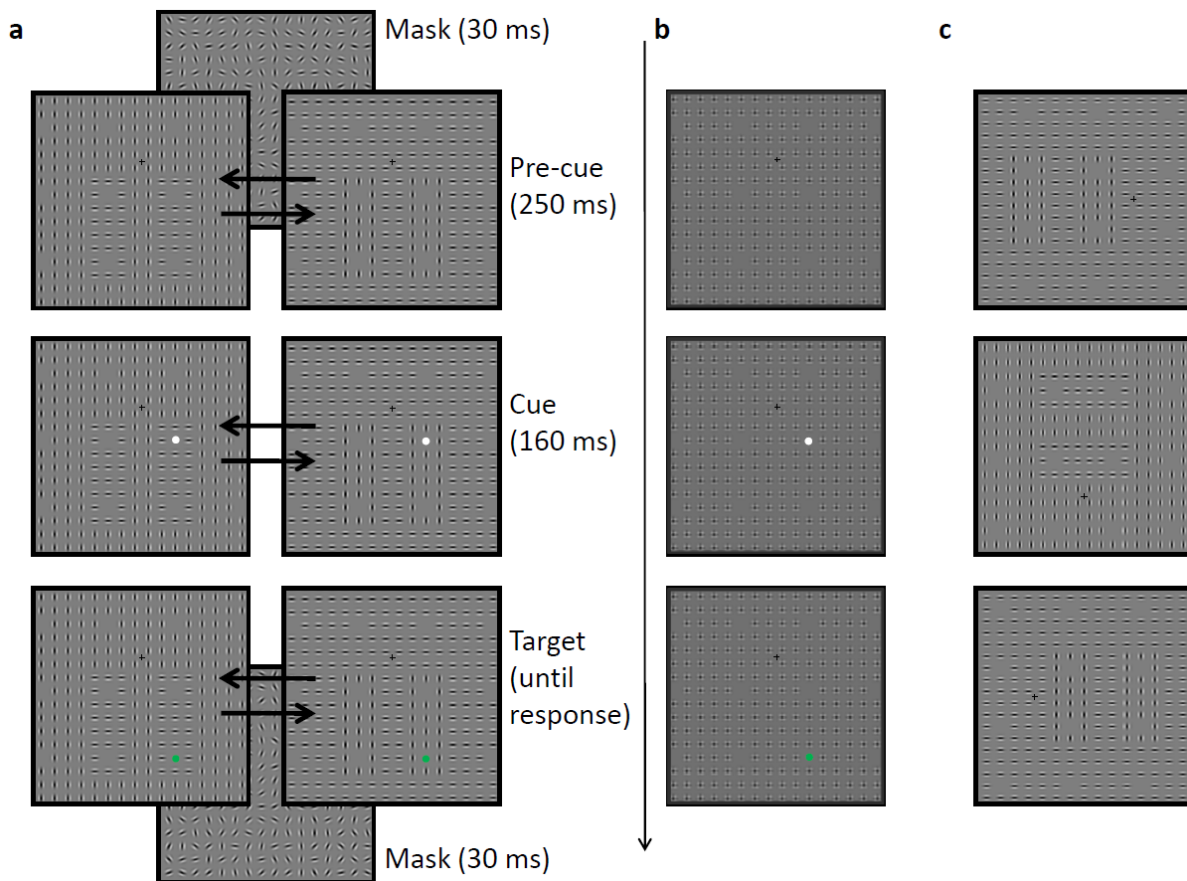
The general methods remained the same as those in experiment 1; however, the objects were smaller and could occupy one of 4 potential positions on each trial and could be either vertically or horizontally oriented. The background lattice was thus extended to consist of 22 x 22 Gabor patches (diameter of 0.4° and spatial frequency of 3.75 cycles/degree) and contained 16 cue/target placeholders distributed in a 4 x 4 arrangement centred on the fixation cross with each one separated by 4 Gabors from its neighbours (vertically and horizontally). 16 placeholders were included across the display, instead of 4, such that the objects could be placed at a number of potential locations across the display. Specifically, 4 locations were used in which the objects could be defined: above, below, left or right of fixation. The figures measured 8 x 3 Gabor patches separated from one another by 2 Gabor spaces. See **figure 3** for an illustration of the stimuli. The location of the pair of figures would be randomly determined with equal probability on each trial. Three target locations were used; valid (50% of trials), invalid-within (25%) and invalid-between (25%). The temporal sequence of the experiment was identical to that of the first (and that reported in Norman *et al*, 2013).

There were four potential object locations: one placeholder was located at each end of both figures and the spatial distance between these placeholders was equated. For each block of trials, the objects were presented an equal number of times vertically and horizontally and the order of this was randomised within each block. On each trial, the location of the objects was determined randomly with equal probability. See **figure 4 (a and b)** for a depiction of the display sequence and a simulation of the observers' perception during the sequence, respectively. **Figure 4c** also shows examples of the different positions and orientations which the objects could assume.

Participants completed 10 practice trials followed by three blocks of 120 experimental trials. Participants were then asked an open question to probe their visual experience of the stimuli: they were asked to describe anything they noticed about the flickering background on which the white flash (cue) and coloured disc (target) were presented. After answering the question, participants were then shown the display with a much reduced alternation rate of 4 Hz which explicitly revealed the nature of the objects in the display.

The second phase of the experiment determined whether participants could identify "within-object" trials from "between-object" trials in a confidence-rating signal-detection procedure. Participants were presented with an additional 3 blocks of 120 trials, preceded by 10 practice trials, each containing the same proportion of valid, invalid-within and invalid-between trials, and the same number of horizontally and vertically presented objects as in the previous attention task. Other randomly-determined parameters (e.g. object position and orientation) and temporal characteristics remained consistent with the attention task. The display duration was set according to the same procedure as the previous experiment. Participants had to indicate on which trials the cue and target

appeared in the same object or in different objects by pressing one of two keys, and then to rate their confidence with that judgment on a scale of 1-4, by pressing one of four keys.



**Figure 4** Illustrations of the stimuli and the temporal sequence of experiment 2; a simulated observer's perception of those events; and three examples of the different object positions and orientations. **a)** Full illustration of the trial sequence. Note that each box only shows a magnified portion of the entire stimulus display, focussed on the objects. Here the objects appear below the fixation cross in a vertically-aligned arrangement and the target is invalidly cued within those objects. Double arrows indicate that the two frames are presented continually in alternation at a frequency of 16.7 Hz. In the signal-detection task, the final two frames (target frames) were only presented for a limited amount of time that was calibrated for each participant (see **Methods**) **b)** A simulated observers perception of the

sequence shown in **a**. Participants are not aware of the presence of the figures. **c**) Examples of the three object positions not shown in **a**; relative to the fixation cross, they are left, above and right. The cue and target on each trial would only be presented within the 4 placeholders associated with the figures.

## Results and discussion

RTs were trimmed using the same methods as in the previous experiment. Overall, 8.6% of all trials were discarded using these methods. A within-participant ANOVA with the single factor Cue Validity was conducted on the mean values of the remaining RTs, with overall means of 421.5ms (valid), 440.1ms (invalid-within) and 446.9ms (invalid-between) as shown in **figure 5a**. The main effect was significant ( $F_{(2,38)}=28.99$ ,  $p<0.001$ ) indicating that the cue had a different effect on participants' RTs depending on its position relative to the target and the figures. In the key analysis, a paired t-test revealed that RTs were shorter on invalid-within than for invalid-between trials ( $t_{(19)}= 2.24$ ,  $p=0.037$ ), indicating that participants were faster to respond to targets that appeared within the same object as the preceding cue relative to those that appeared on a different object. No significant effect of accuracy (valid: 96.3%, invalid-within: 96.1%, and invalid-between: 96.8%) was found between the conditions of cue validity ( $F_{(2,38)}=0.45$ ,  $p=0.639$ ), indicating no trade-off between RT and accuracy.

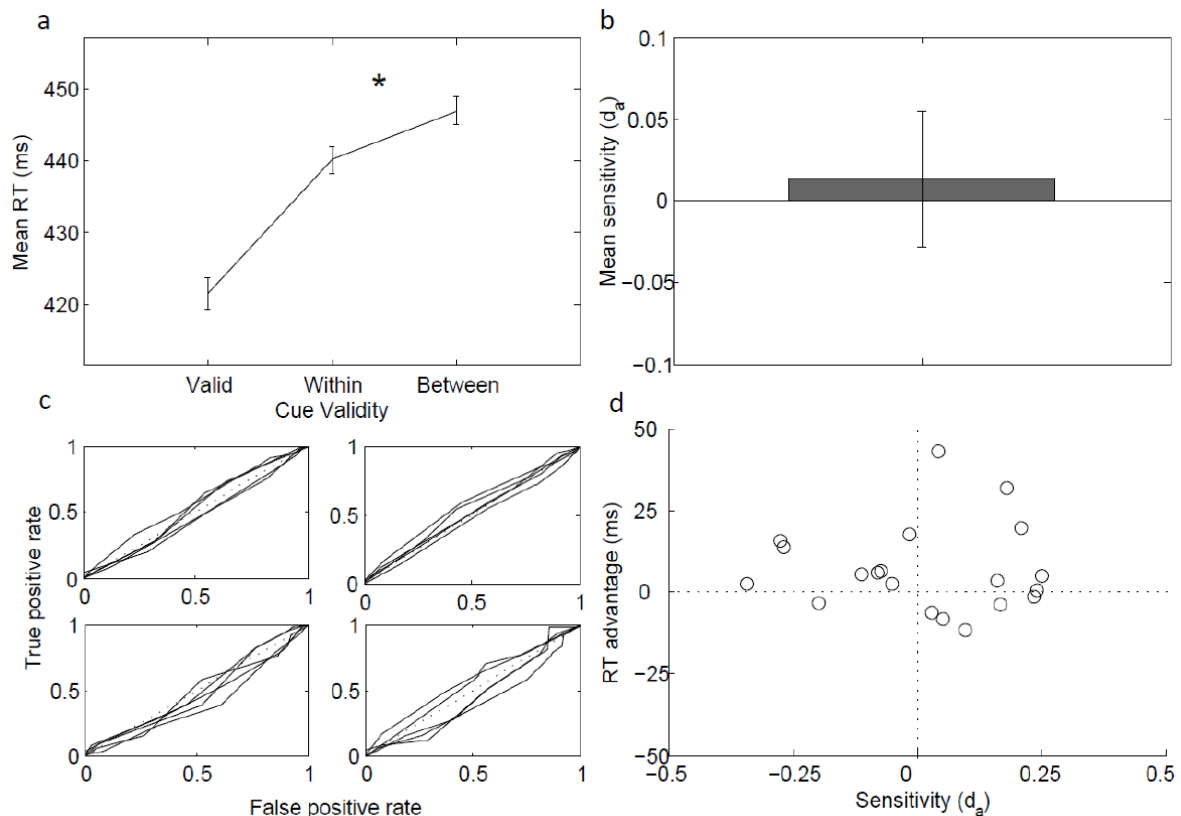
Data from the subsequent signal-detection task were used to formally measure participants' sensitivity to the objects. The task measured participants' ability to distinguish two categories of trial ("within-object" and "between-object") that each occurred an equal number of times. For the purposes of signal-detection, this is analogous to a yes/no design, in which "between-object" trials are treated as "signal-present" and "within-object" trials are treated as "signal-absent (noise)". With this design, sensitivity ( $d_a$ ) was calculated in the

same way as in the previous experiment. Overall, participants'  $d_a$  (shown in **figure 5**) did not differ significantly from zero (mean  $d_a = 0.01$ , with average confidence intervals of  $\pm 0.035$ ;  $t_{(19)} = 0.32$ ,  $p = 0.75$ ), indicating that participants could not discriminate the two conditions of within-object and between-object trials, and hence it is extremely unlikely that they had any awareness of the objects. The ROC curves are plotted in **figure 5** and, as shown, no participant showed any ability to maximise hit rate whilst minimising false alarm rate (as would be indicated by a bowed curve), indicating that they could not accurately distinguish the conditions that were driving the object-based attention effects in the previous task. We performed the same Bayesian model comparison as in experiment one and calculated a Bayes factor of 0.01, which again is in support of the hypothesis that participants had no awareness of the objects.

**Figure 5** also shows a scatterplot of points for each individual participant's within-object RT advantage (calculated from between-object RT – within-object RT) versus sensitivity ( $d_a$ ). A parametric correlation test between these two variables is not significant ( $r(18) = -0.019$ ,  $p = 0.935$ ), clearly indicating no association between the awareness of the objects and their effect on attention.

The results from this experiment show that when parity is optimised between the separate tasks measuring attention and awareness then the dissociation between object-based attention and object awareness still holds. This strongly suggests that the nature of the task given to participants in the signal detection phase of the experiment is unlikely to account for the dissociation between attentional effects on performance and measured awareness.





**Figure 5:** Results from both the attention task and signal-detection task from experiment 2. **a)** RT results from the attention task (N=20). Participants were quicker to identify the colour of a target when it appeared within the same object as a preceding cue compared with when it appeared on a different object, whilst spatial distance was equated. This is true despite participants denying any awareness of those objects. Asterisk denotes a significant paired t-test at the 5% level. Error bars show 1 standard error of the mean with between-participant variance omitted **b)** Average sensitivity ( $d_a$ ) to the difference between within- and between-object trials. This value is not statistically different from 0, indicating absence of awareness. **c)** Individual participants' ROC. All participants show an approximate linear plot indicating that they could not successfully maximise hit rate whilst minimising false alarm rate. Each set of axes represents 5 of the total 20 participants' ROC curves. **d)** Scatterplot of each participant's RT advantage (between-object RT - within-object RT) versus sensitivity. There is no observable association between the participants' ability to discriminate within-object trials from between-object trials and their difference in RT between the two conditions.

## General discussion

In the first of two experiments we have shown that a truly exogenous form of object-based attention can operate in the absence of awareness. As is typical of many object-based attention tasks, in the version showing object-based attention without awareness reported previously (Norman *et al*, 2013) targets appeared on the cued object more often than on the non-cued object due to the inclusion of the “valid” cue condition along with the critical “within” and “between” conditions. The consequence of this setup, however, is an object-based contingency (targets appeared more often on the cued object) that means that no conclusion can be drawn as to whether the unseen objects was selected on a purely exogenous basis. In experiment 1, following Lee *et al* (2012), we removed this contingency and found that object-based attention (i.e. in the exogenous form it is typically assumed to operate – e.g. see de-Wit, Cole, Kentridge, & Milner, 2011) was present for objects that did not enter participants’ awareness.

The work of Chica and Bartolomeo discussed earlier demonstrate clearly that exogenous attention is a major factor in determining what enters the contents of awareness (e.g. Chica, Paz-Alonso *et al*, 2012), but the results of experiment 1 in the present study demonstrate that stimuli selected by attention in an exogenous manner do not *necessarily* enter awareness. This is in agreement with others that have previously shown some indication that exogenous attention in the absence of awareness might be possible (e.g. Marzouki *et al*, 2007; Van den Bussche *et al*, 2010).

Experiment 1 was successful in controlling for object-based contingencies and showing that a purely exogenous form of object-based attention can operate without the objects entering awareness. The motivation for conducting this experiment was driven by

the possibility that subjects might learn about contingencies in the standard object-based attention paradigm despite their lack of awareness. Two lines of evidence suggest that this is a genuine concern. First, it is known, however, that conscious object-based attention can be modulated by the presence of competing spatial contingencies (Lee *et al*, 2012; Yeari & Goldsmith, 2010) and that contingencies can be learned surprisingly rapidly (e.g. Kristjánsson, Mackeben, & Nakayama, 2001). Second, such contingencies can be learned and effect deployment of attention without subjects becoming aware of them (e.g. Lambert & Sumich, 1996) or even being aware of the stimuli they are learning about (e.g. Lambert, Naikar, MacLachlan & Aiken, 1999).

The second experiment of this study examines the consequences of using a task in the signal detection phase of an experiment on object-based attention without awareness that most closely matches the attentional task in terms of the information that determines performance. In Norman *et al* (2013) we reported results based on a test of participants' ability to discriminate objects' presence versus their absence. Given that the critical property that determines the unconscious attention effect is the positions of the cue and target relative to the object on each trial, this is not the task with the most parity. Experiment 2, therefore, replicated the procedure of Norman *et al* (2013) but with the modification of requiring participants to discriminate "within-object" from "between-object" trials and found no evidence that participants were able to perform in this version of the signal detection task above chance. This experiment, together with that reported in Norman *et al* (2013), demonstrates that for the stimuli used in this design the dissociations previously obtained between attention and awareness could not be accounted by the nature of the signal detection tasks used to measure awareness.

It is important to address the possibility that the within-object advantage does not necessarily reflect the encoding of an object representation by the visual system. Instead, it is possible that the preattentive segmentation of the visual scene based on feature contrasts may result in attention being constrained by the contours of an object in a purely spatial manner. The results of Naber, Carlson, Verstraten & Einhäuser (2011), however, show that the perceptual benefits that are typically assumed to be associated with objecthood (i.e. object-based attention) are not the result of such low-level feature-based representations, but of a representation of an object as a “unique representational entity” (Naber *et al*, 2011, p.6). In the stimuli of their experiment, the percept changed spontaneously between that of a bound object and that of an unbound constellation of features, despite no physical changes in the stimulus. Only when the bound object was perceived was there an object-based facilitation effect at and within the object’s borders. The presence of an “object-based attention effect”, therefore, may be taken as an implication of the encoding of an object representation (i.e. a distinct and single perceptual entity that is not restricted to a spatial reference frame). In conclusion, it is clear that attention can be used to select stimuli that remain unseen. The two experiments reported here advance our understanding of this dissociation first by showing that object selected under purely exogenous control do not necessarily enter awareness and second by showing that such results are not merely a consequence of the nature of the task used in measuring awareness.

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